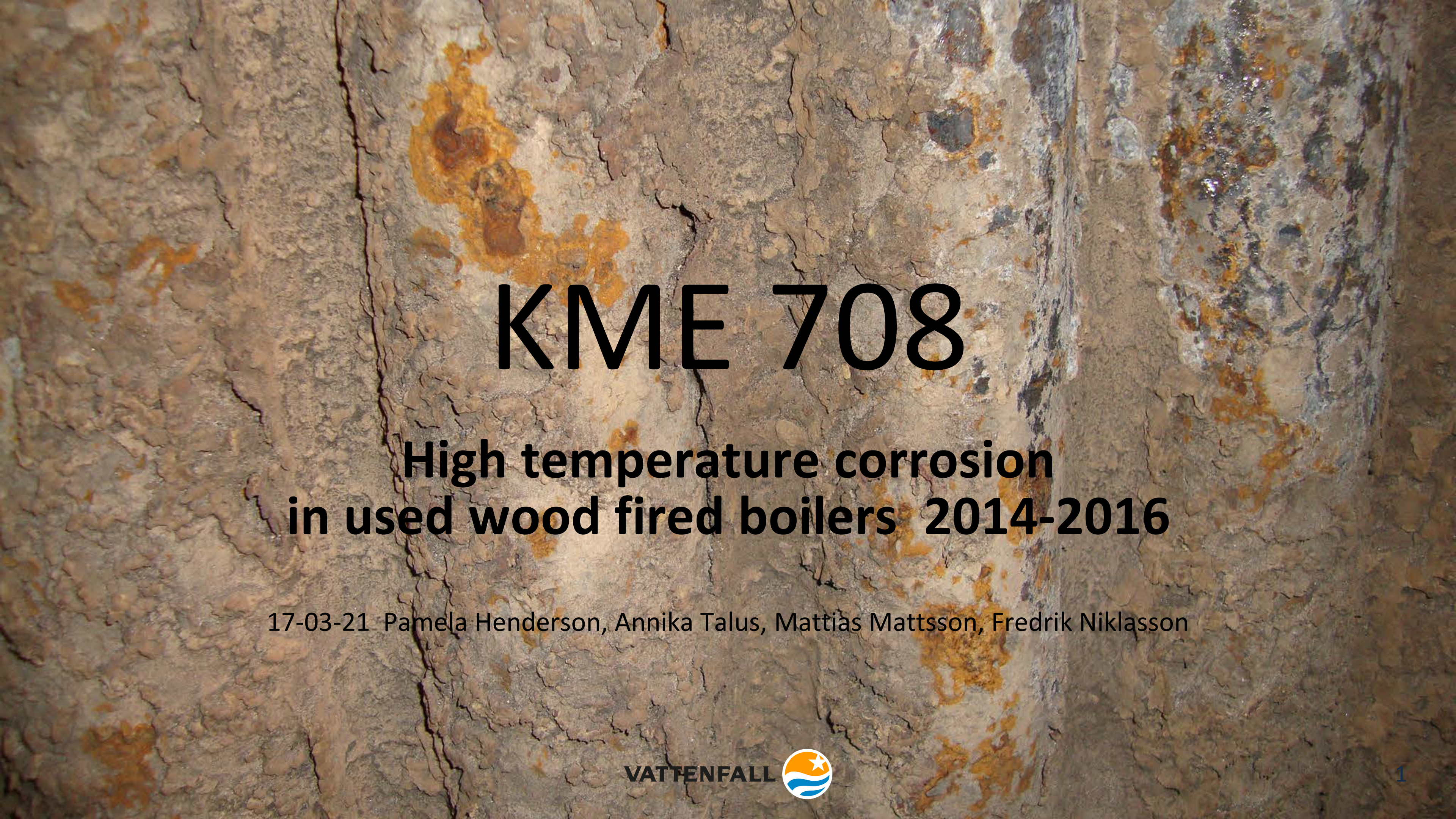

# KME 708

## High temperature corrosion in used wood fired boilers 2014-2016

17-03-21 Pamela Henderson, Annika Talus, Mattias Mattsson, Fredrik Niklasson

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# SCOPE AND GOALS

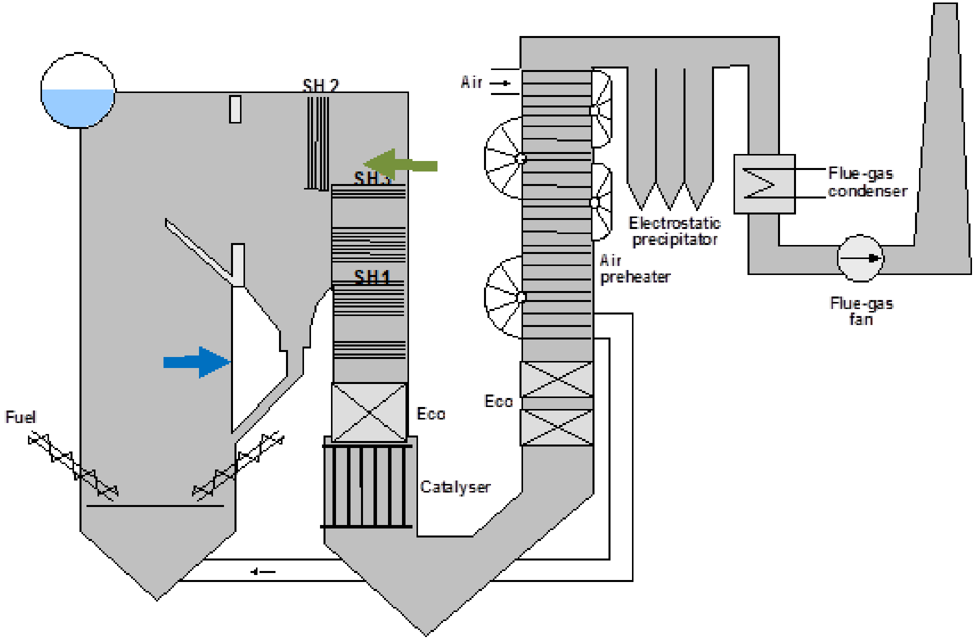
The overall objective of the project was to reduce high temperature corrosion, in a cost-effective way, in heat and power boilers that burn predominantly used (recycled ) wood. To achieve this the following goals were set :-

1. finding wall coating materials that are more cost-effective (i.e.cheaper or more corrosion resistant) than conventional nickel-base alloys like Alloy 625. A cost or corrosion rate reduction of 20% was aimed at.
2. evaluating materials that are suitable for high temperature superheaters
3. from results of short-term testing (performed in 508) with digested sewage sludge decide to proceed (or not) with long-term testing of sludge as an additive, i.e decision to run part 2 (KME 718).
4. **obtaining a better understanding between fuel quality (fuel chemistry) and corrosion**

# PARTICIPANTS

- Vattenfall Research and Development: Project management, probe testing
- Vattenfall Nordic Heat: plant owner, corrosion testing, fuel supply
- Sandvik Materials Technology: supply of materials
- Sandvik Heating Technology: supply of materials
- E.ON: plant owner , corrosion testing
- Fortum: plant owner, activities to reduce corrosion
- Foster Wheeler: boiler manufacturer, corrosion testing
- KTH: microscopy, analysis, ThermoCalc 2014-15
- KIMAB: microscopy, analysis – took over after KTH  2015-16
- SP: fluidised bed reactor – fuel quality testing

# Fuel Quality Testing performed in Idbäcken line 3 (CHP) in Nyköping




**Bubbling Fluidised Bed**

**70 $MW_{heat}$ 35 $MW_{el}$**

**Design steam data: 140 bar/540°C**

**Fuel : 100% used wood**
**(cheaper than forest fuel, but more corrosive)**



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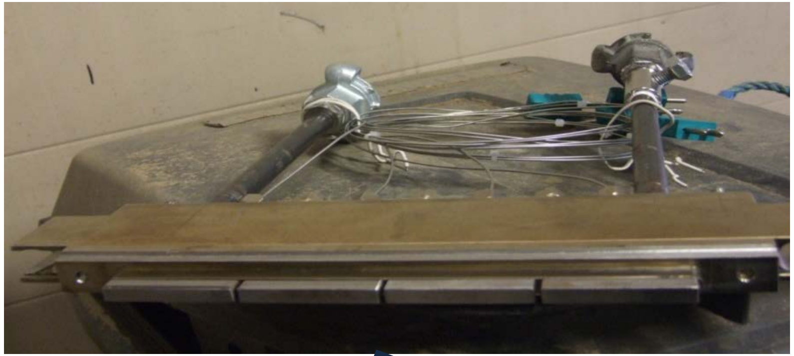
# Fuel quality testing in Idbäcksverket CHP 100 MW

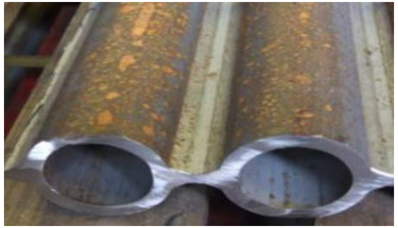
- Two fuel grades. 2 x 2 weeks tests. 2 wall probes each test, 350°C and 400°C. 2x16Mo3 and 2x Alloy 625 on each probe.
- Also 3 h deposit probe tests near superheaters

| | Moisture % | Ash % d.s. | Cl % d.s. | S % d.s. | N % d.s. | K ppm d.s. | Na ppm d.s. | Pb ppm d.s. | Zn ppm d.s. |
|---|---|---|---|---|---|---|---|---|---|
| **Used wood 1** | 34.9 | 6.2 | 0.13 | 0.07 | 1.1 | 1141 | 1783 | 36 | 390 |
| **Used wood 2** | 22.3 | 6.9 | 0.17 | 0.07 | 1.5 | 927 | 1019 | 119 | 111 |

UW 1 – low Cl, low Pb, higher Zn. UW 2 - high Cl, high Pb, lower Zn
These fuels were supplied to SP for laboratory testing

# Vattenfall's corrosion probe testing – air-cooled furnace wall probe





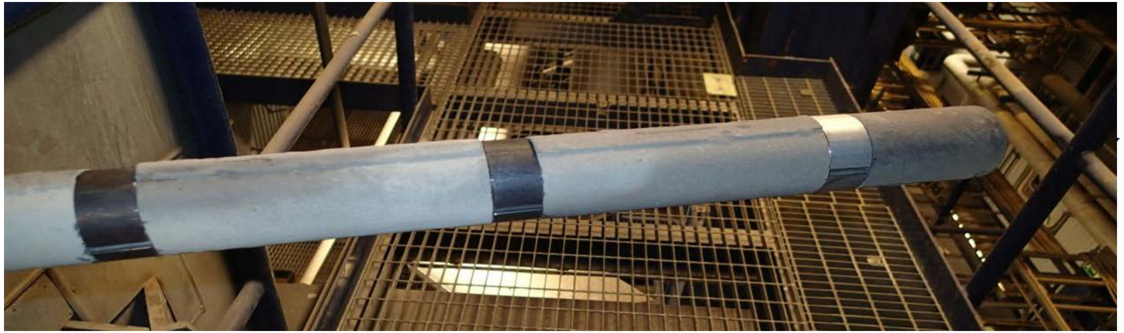
Vattenfall's in-house probe. Sits between the tubes in the furnace wall. 4 specimens  on each probe. Thermocouple in each specimen for individual temperature measurement. Control temp 350 and 400°C

2-week tests

# Vattenfall's deposit probe testing in SH region

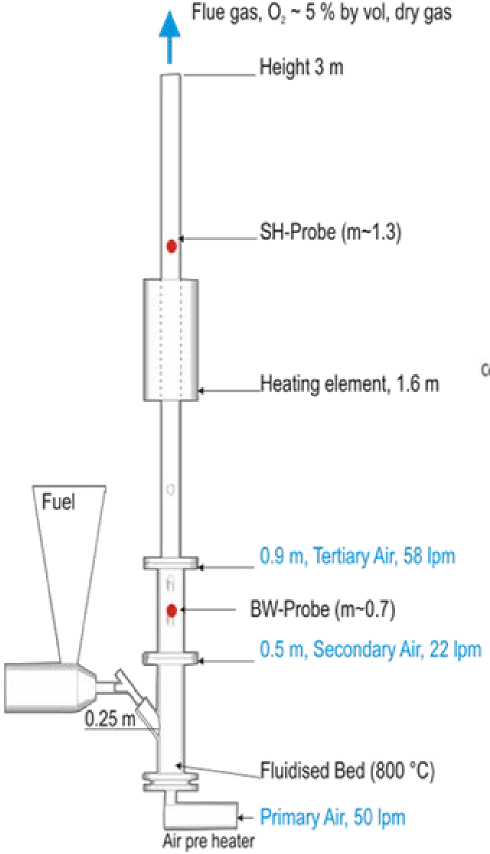
## Air cooled probe – 3 hour tests

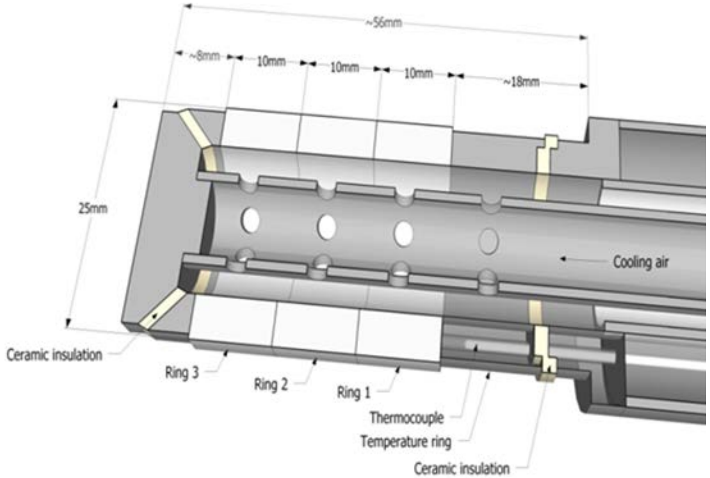
Three rings at temperatures 350, 450, 550°C
(equivalent to steam temp ~520°C)



- Weigh ring before and after exposure for deposit growth rates.
- Analyse deposit with SEM for info on corrosion risk

# AND FUEL QUALITY TESTING IN SP'S LABORATORY RIG




Fluidised Bed
10 kW Height 3m

8-hour tests
380°C at furnace wall
550°C superheater

| | Fuel 1 | Fuel 2 |
|---|---|---|
| Furnace wall (380 °C) |  |  |



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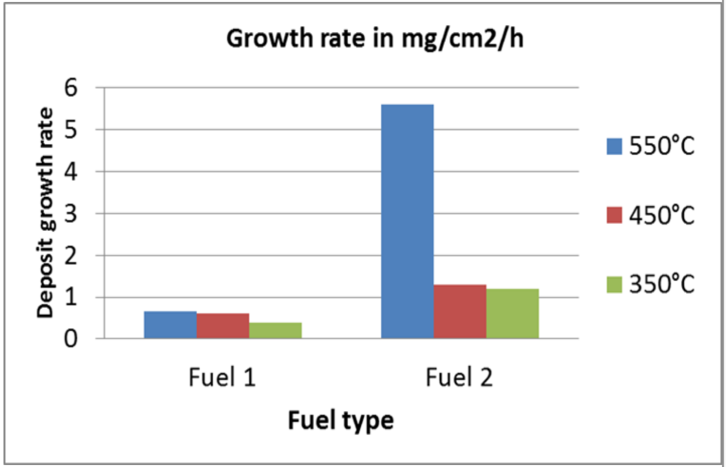
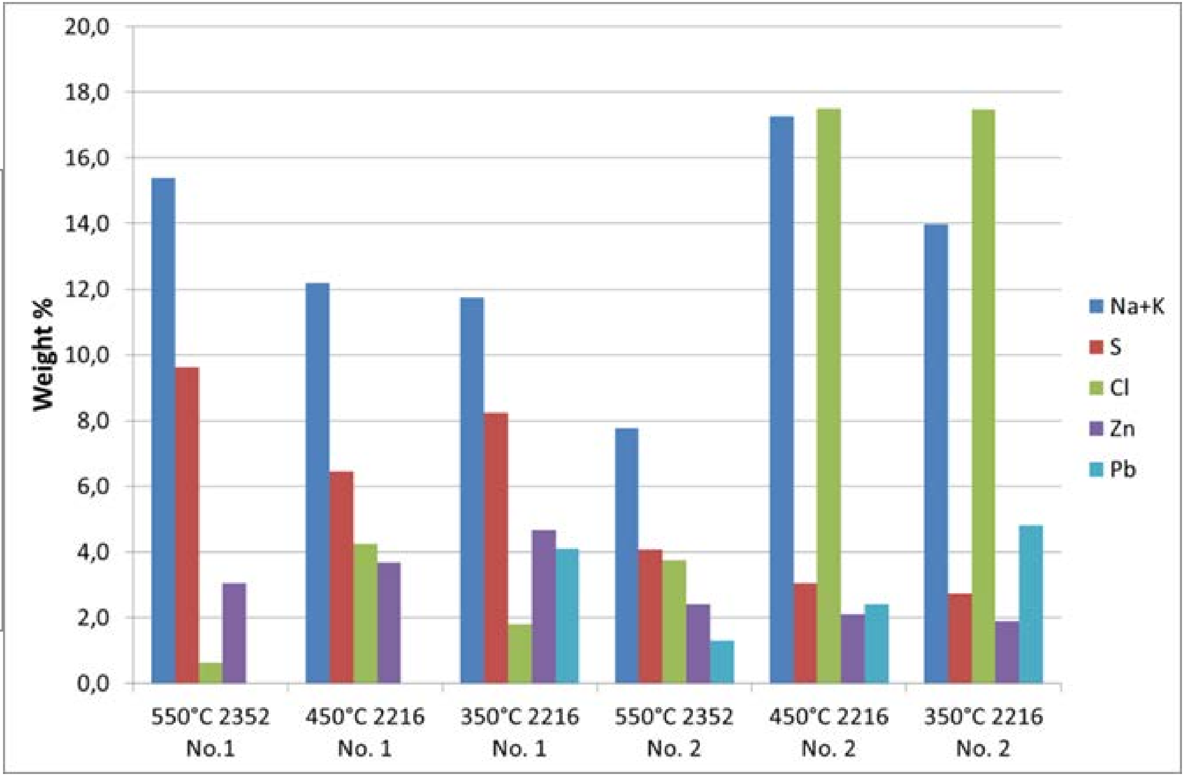
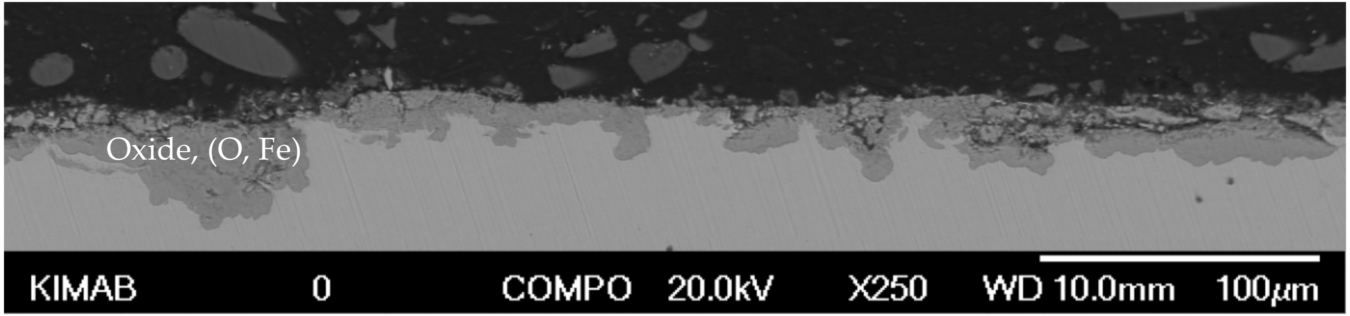
# Fuel quality - 3 hour deposit testing near SH in 100MW CHP

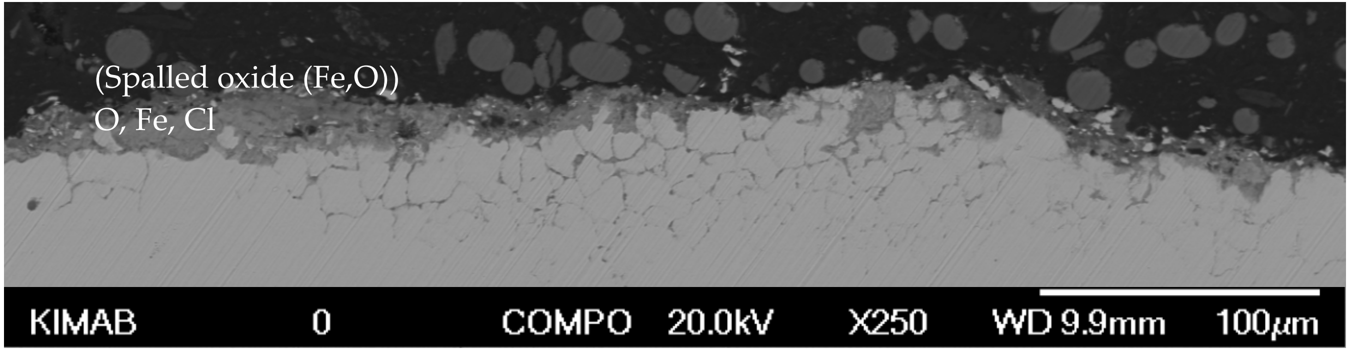


# Fuel quality - 3 hour deposit testing near SH – 13CrMo44 350°C

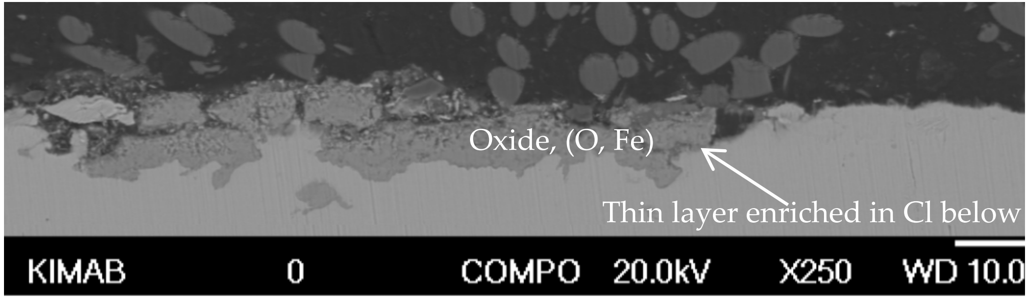



Fuel 1

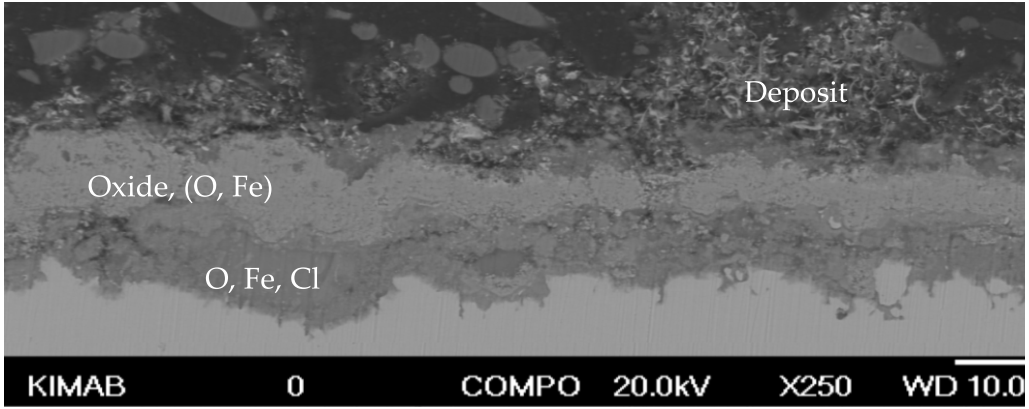



Fuel 2

# Fuel quality - 3 hour deposit testing near SH – 13CrMo44 450°C

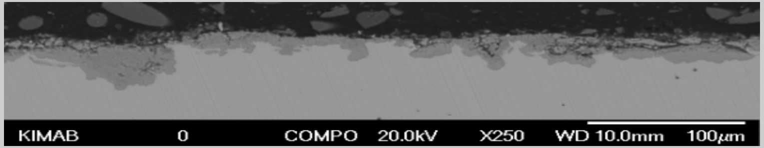
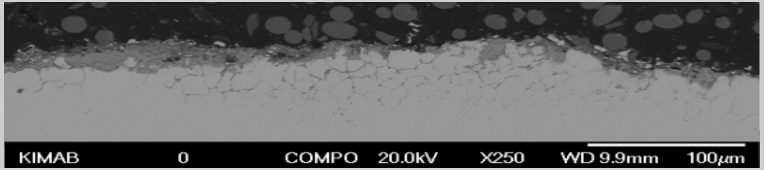



Fuel 1




Fuel 2

# Superheater 3h cross-section appearance summary

<table>
<tr><th></th><th></th><th>Low Pb/Cl</th><th>High Pb/Cl</th></tr>
<tr><td rowspan="2">2216</td><td>350</td><td>
</td><td>
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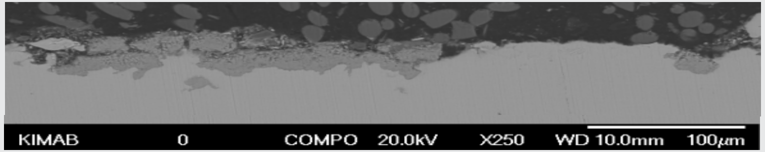
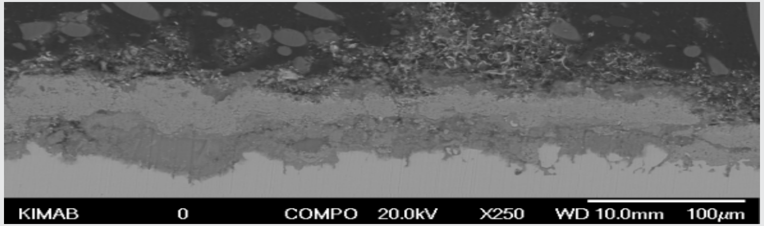
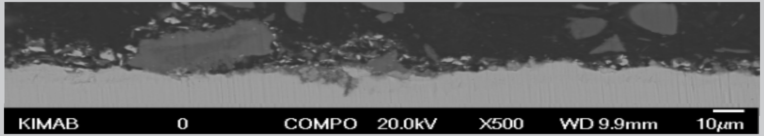
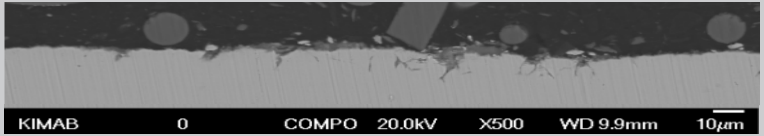
<tr><td>450</td><td>
</td><td>
</td></tr>
<tr><td>2352</td><td>550</td><td>
</td><td>
</td></tr>
</table>

For all temperatures the corrosion increases with higher Cl/Pb-content in the fuel.
Corrosion low in both cases for stainless steel at 550°C.
SS2216 =13CrMo44, SS2352 = TP304L



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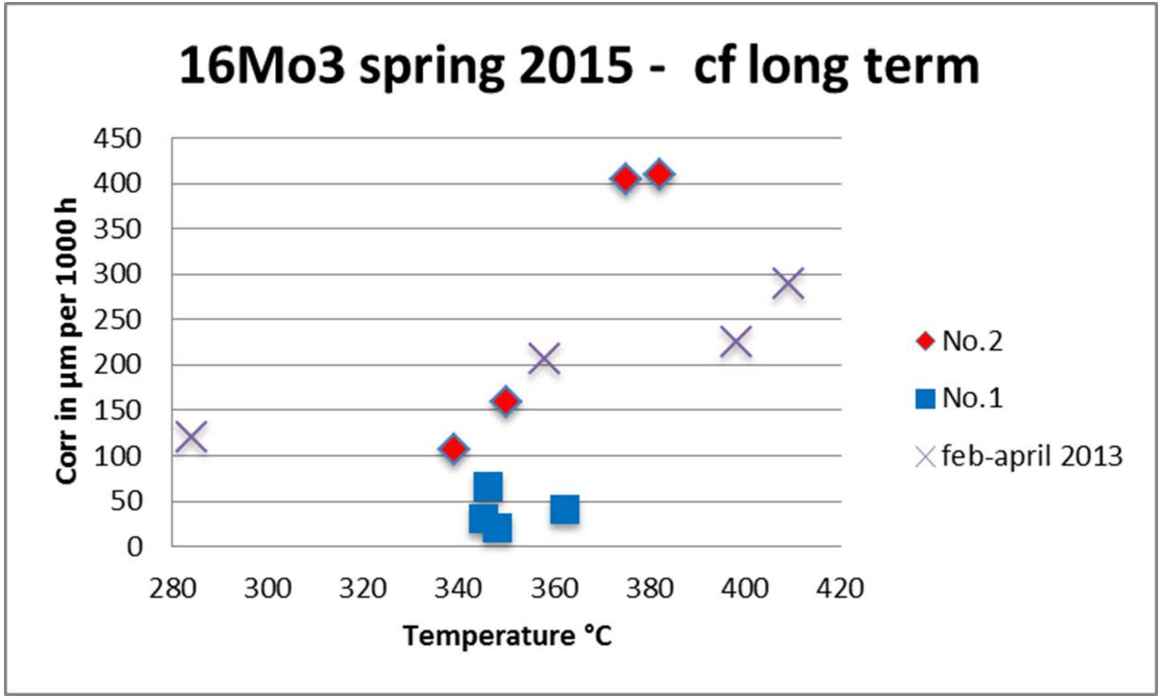
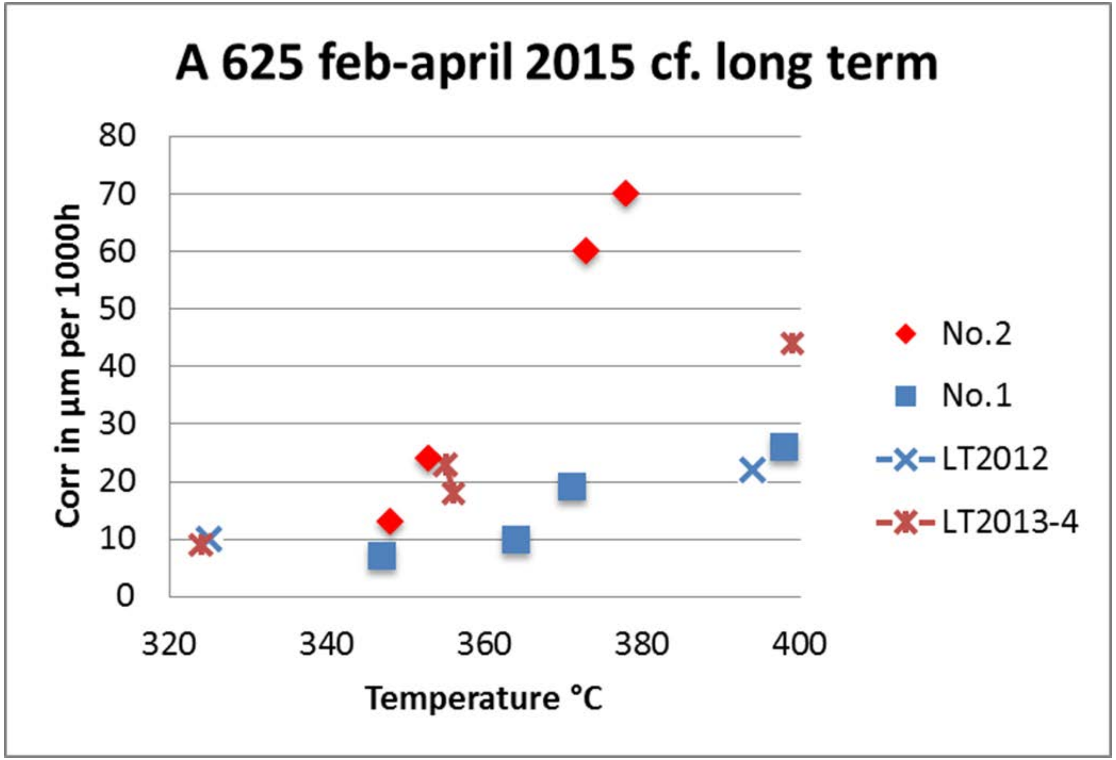
# Fuel quality – 2 week corrosion testing at furnace wall




Fuel no. 2 (High Cl and Pb) causes more corrosion on 16Mo3 and is more temperature sensitive.

6 times more corrosion at the highest temperature

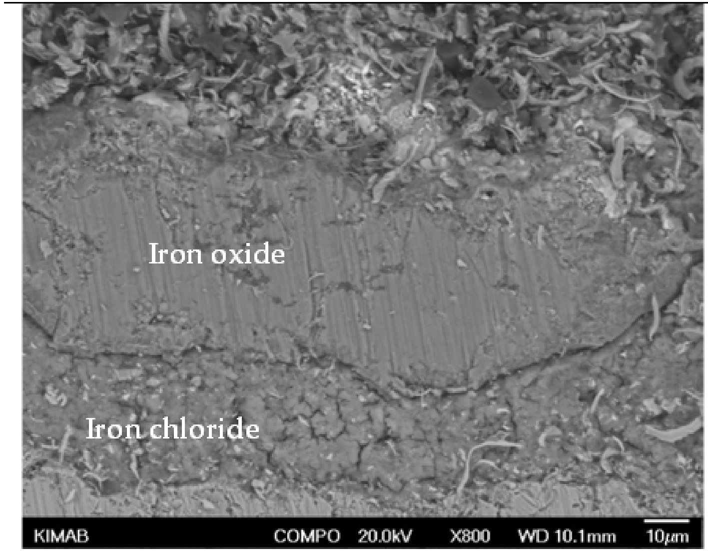
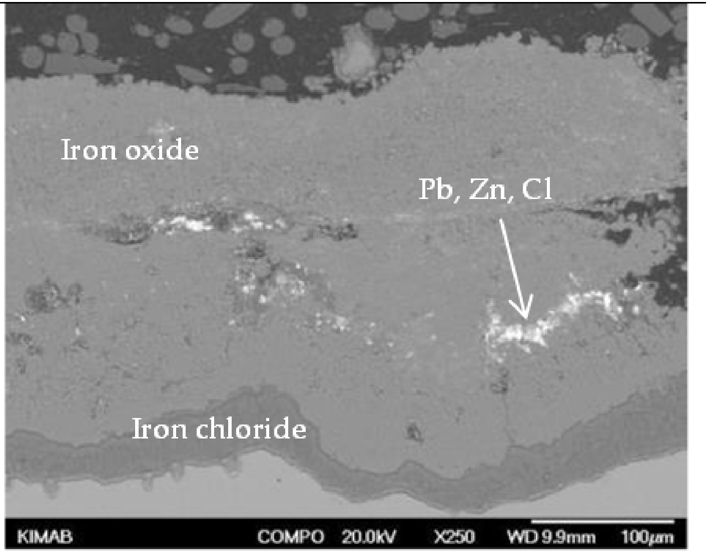
# Fuel quality – 2 week corrosion testing at furnace wall




Fuel no. 2 (High Cl and Pb) causes more corrosion on Alloy 625 and is more temperature sensitive.

3 times more corrosion at the highest temperature.

# Fuel quality – 2 week corrosion testing furnace wall 16Mo3 350°C

| Fuel 1 | Fuel 2 |
|---|---|
|  |  |
| a) | b) |

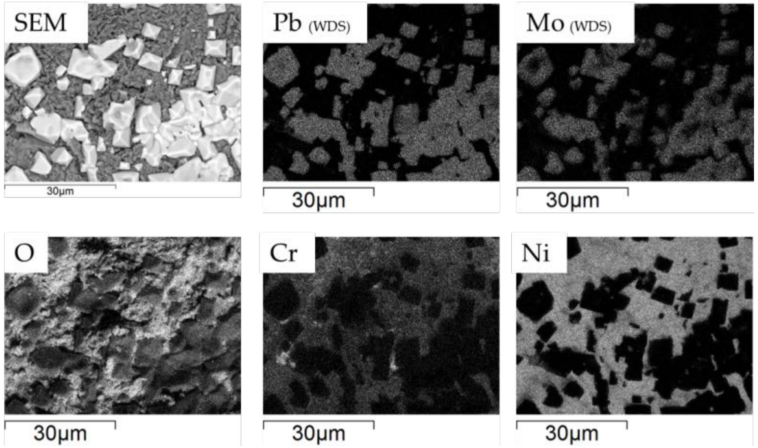


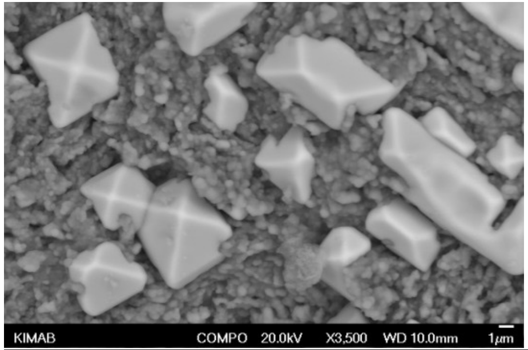


For 16Mo3, iron oxide and iron chloride were found as corrosion products and Pb-rich compounds were found in the samples exposed to Fuel 2, but not Fuel 1.

Note: a) is at higher magnification than b

# Fuel quality – 2 week corrosion testing furnace wall  A625 370°C

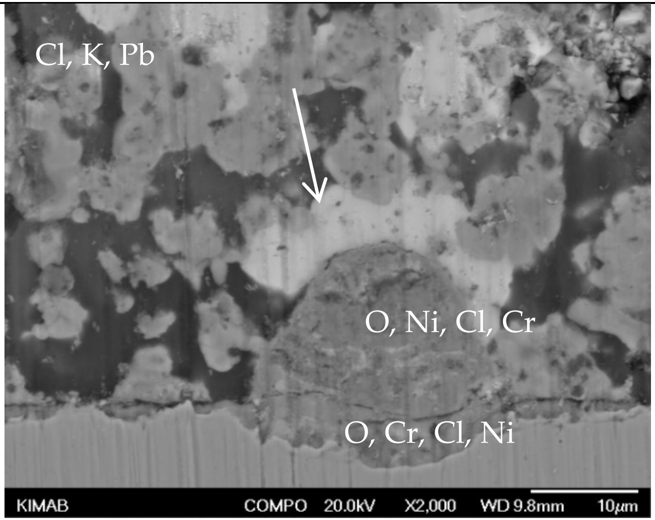
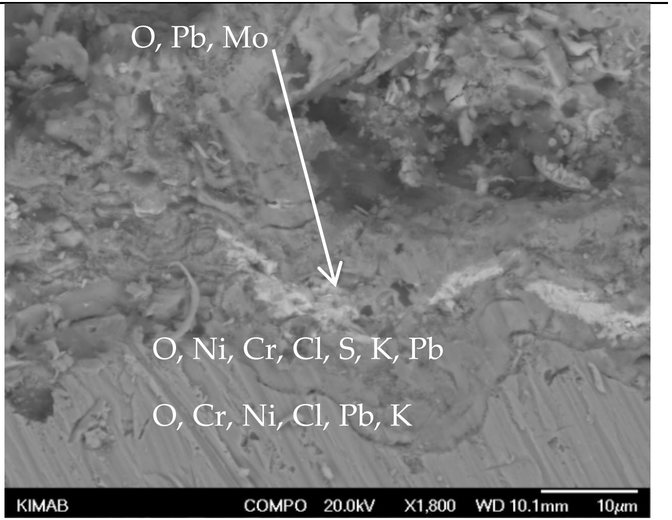



| at% | O | Cr | Ni | Mo | Pb |
|---|---|---|---|---|---|
| crystals | 72 | 2 | 3 | 10 | 12 |
| matrix | 61 | 5 | 32 | 1 | 1 |

Lead molybdate, $PbMoO_4$, was found on the surface and in the cross sections of Alloy 625 samples exposed in Fuel 2 at temperatures of 370°C and higher. $PbMoO_4$ was identified by EDS analysis and X-ray diffraction.

# Fuel quality – 2 week corrosion testing furnace wall A625 350 - 370°C

| | 350 °C | 370 °C |
|---|---|---|
| Local corrosion attack |  |  |



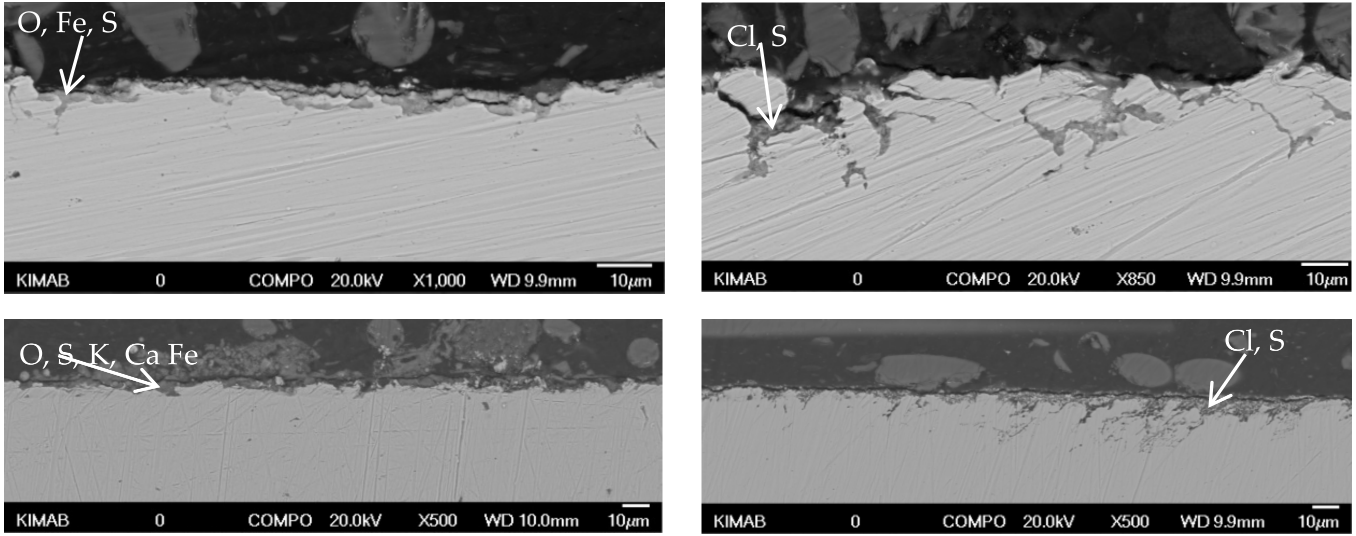
At lower temperatures (350 °C) no lead molybdate $PbMoO_4$, was found in the corrosion products but compounds rich in Pb, K and Cl were often found in a deposit -alloy mixture

# Fuel quality – 8 hour testing in lab. 10kW. Superheater 550°C

Fuel 1 | Fuel 2

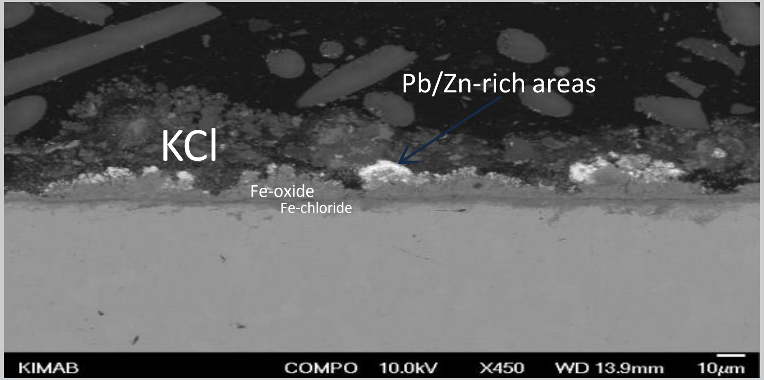
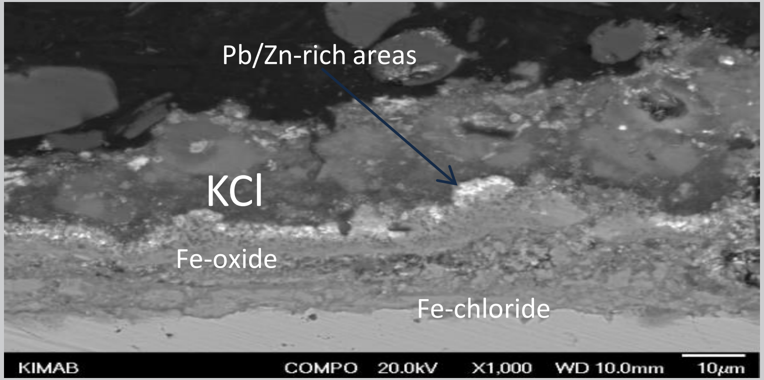
2,25Cr

304L




More Cl detected at corrosion front and more internal corrosion with Fuel 2.

# Fuel quality – 8 hour testing in lab. - Furnace wall 380°C – 16Mo3

| | Low Cl/Pb | High Cl/Pb |
|---|---|---|
| 16Mo3 |  |  |

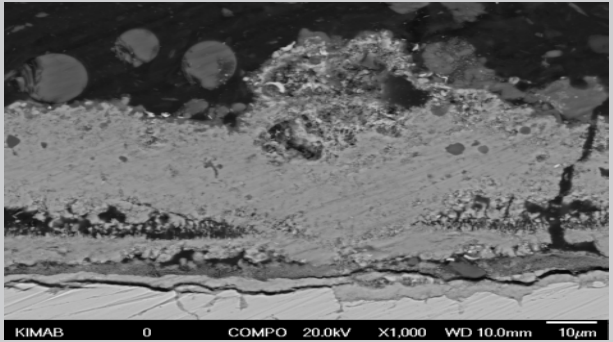
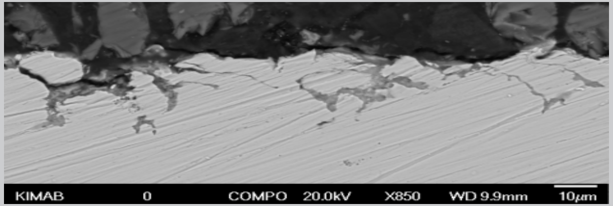
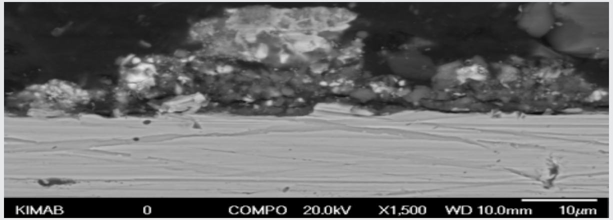
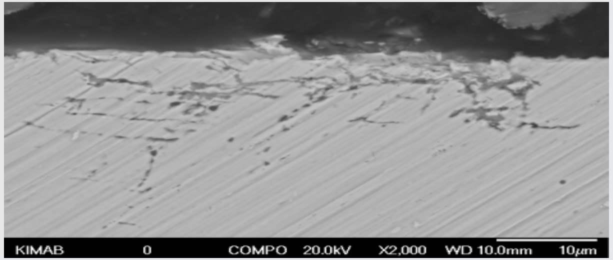




Results show that the corrosion increases when Pb/Cl-content in the fuel increases even though not dramatically after 8 h. Fe-chloride layer is thicker for Fuel 2

(Note the difference in magnification between the figures)

# Fuel quality – 8 hour testing in lab - Superheater 550°C

| | Low Cl/Pb | High Cl/Pb |
|---|---|---|
| 2.25Cr |  |  More internal oxidation with Cl in grainboundaries. Spalled samples, according to SP in oxide/metal interface. |
| 304L |  |  Cl and internal oxidation |

No clear corrosion for Sanicro28 after this short exposure time

# Summary – fuel quality testing

Plant and laboratory testing in qualitative agreement.

Small differences in chlorine and lead content in used wood resulted in large differences in the corrosion rate. Higher Cl- and Pb-levels gave higher corrosion rates and the difference increased with increasing metal temperature.
Corrosion of 16Mo3 was more sensitive to Cl/Pb content than corrosion of Alloy 625.
Corrosion can be reduced by careful control of the fuel composition and by reducing the furnace wall temperature (reducing boiler water pressure).

The lead concentration in the deposit increased towards the metal substrate. A thinner (spalled) deposit showed higher concentrations of lead. Evaluating the corrosion risk based on surface deposit composition needs to be performed with care and in combination with cross-sectional analyses. Lead molybdate, $PbMoO_4$, was found in Alloy 625 after plant tests at 370°C and above.

# Summary – material testing

Superheaters - Austenitic stainless steels and nickel-based alloys performed well as superheater materials or coatings for superheaters when firing recycled wood. Ferritic steels (up to 12% Cr) are not suitable in an uncoated condition.

Furnace wall - Sanicro 33 showed lower corrosion rates than Alloy 625, but only two tests were performed. Kanthal APMT and Sanicro 28 have been tested many times and showed similar (although more variable) corrosion rates to Alloy 625. These three alloys are estimated to be 25-30% cheaper than Alloy 625.

Sandvik is able to weld APMT on to a furnace tube. Testing with several coatings on a wall tube is on-going in a power plant in UK. The results will be evaulated in the continuation project KME 718. Testing of coated materials on probes and long-term effects of digested sewage sludge and fibre sludge are also being evaluated KME 718.

The project KME 708 finished on 31 December 2016.

Thank you for your attention